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Outdoor Testing of Type I Fluids in Snow

September 2002

Final Report

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U.S. Department of Transportation
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16. Abstract

Outdoor testing of five SAE Type I ground aircraft deicing fluids were conducted for natural snow in Chicoutimi, Quebec, Canada, between January and March 2002. These tests were performed using aluminum boxes which were shown to be thermodynamically equivalent to a wing leading edge coated with fluid. For these tests, the boxes were coated with 0.5 L of Type I fluid heated to 60°C and applied to the test surface by means of a specially made spreader. The objective of this investigation was to conduct outdoor testing and determine the anti-icing endurance times of five Type I deicing fluids under natural snowfall conditions on wing thermodynamic equivalent boxes. Testing was performed on five fluids, three of which were diluted to a 10° buffer with the outside air temperature, according to dilution charts provided by the manufacturer, the other two were premixed fluids and were tested as received, without further dilution. Tests were performed during 18 natural snow events. Most of them occurred at temperatures between -3.5° and -15.0°C producing fine snow with stellar and spatial dendrite crystal types in the <1 mm size range. The results showed that, given the scatter of results under natural conditions, all five fluids had relatively similar endurance times; the greatest difference of 40% being observed between fluids with the longest and shortest times, with the same intensity. The prediluted fluids had, in general, longer times by about 20%, as compared to the fluids tested at a 10° buffer with the outside air temperature. Results were compared to those obtained at the APS Aviation site, where events occurred at warmer temperatures, which led to longer endurance times. However, when the temperature differences are taken into consideration, the times are comparable. The data at both sites generated the following holdover times for various temperature ranges:

- above 0°C 11 to 18 minutes
- 0° to -3°C 6 to 11 minutes
- -3° to -10°C 4 to 7 minutes
- below -10°C 2 to 4 minutes

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EXECUTIVE SUMMARY

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- below -10°C 2 to 4 minutes

1. INTRODUCTION.

The Federal Aviation Administration's William J. Hughes Technical Center continues to support research and related efforts directed toward the improvement of aircraft deicing methods and practices. One such effort is the standardization of Holdover Time (HOT) table guideline test procedures for deicing/anti-icing fluids. Previous HOT testing for snow was produced by running outdoor tests on flat plates and reporting the values in the table guidelines. This method was shown to generate conservative, but equivalent times for Type II anti-icing fluids [1]. However, when the method was applied to Type I deicing fluids, the times were considered unrealistically short by the SAE G-12 Holdover Time Subcommittee. The times previously determined were in the order of 6 to 15 minutes, compared to 3 to 6 minutes on flat plates.

Since these times were much shorter than expected, tests were performed to find a more representative test substrate. This was determined to be an aluminum box [2] considered to be a wing leading edge thermodynamic equivalent, with a similar temperature degradation profile to the leading edge of aircraft wings coated with heated Type I fluids.

1.1 OBJECTIVE.

The objective of this investigation was to conduct outdoor testing and determine the anti-icing endurance times of five Type I deicing fluids under natural snowfall conditions on wing thermodynamic equivalent boxes.

1.2 SCOPE.

The scope of this project consists of outdoor endurance time testing of Type I aircraft deicing fluids under natural snowfall conditions.

2. METHODOLOGY.

2.1 TEST FLUIDS.

The tests were conducted on five fluids from two fluid manufacturers (see table 1). Three of the fluids were concentrates: Octagon Octaflo EF, Dow UCAR ADF (PG), and Dow UCAR ADF (EG). These were tested to a 10° buffer of the freeze point to the outside temperature, according to recommended dilution charts provided by the fluid manufacturers. The other two fluids, Octagon Octaflo EF Pre-mix 55/45 and XL-54, were premixes and were used as received without further dilution for all temperatures. XL-54 was provided by the manufacturer, while Octagon Octaflo EF was mixed at the Anti-icing Materials International Laboratory (AMIL) from E099 to a dilution of 55/45 using tap water, as instructed by the manufacturer.

For typical fluid/water dilution mixtures, the Water Spray Endurance Tests (WSET) were performed according to AMS1424D Annex A [3] and presented in table 2. These tests were performed to ensure the fluids were SAE Type I fluids with a minimum required WSET time of 3 minutes. The table shows that for all dilutions tested, the WSET times exceeded the 3-minute minimum. To characterize the fluids, the viscosities of the same dilutions were measured according to ASTM D 445 at 20° and 0°C. The results are presented in table 3.

TABLE 1. FLUID IDENTIFICATION

Company Name	Fluid	Color	AMIL Label	Reception Date
Octagon Process Inc.	Octaflo EF Concentrate	orange	E099	2001-04-12
Octagon Process Inc.	Octaflo EF Pre-mix 55/45	orange	E509	2001-04-12
Dow Chemical Company	UCAR ADF (PG) Concentrate	orange	E382	2001-10-09
Dow Chemical Company	UCAR ADF (EG) Concentrate	orange	E143	2001-06-01
Dow Chemical Company	XL-54 as received	orange	E165	2001-06-14

TABLE 2. WSET TIMES FOR SOME DILUTIONS OF FLUIDS TESTED

Fluid	Dilution	WSET
Octagon Octaflo (EF)	65/35	6 min 45 sec
Octagon Octaflo (EF)	50/50	5 min 23 sec
Dow UCAR (PG) ADF	65/35	5 min 18 sec
Dow UCAR (PG) ADF	50/50	4 min 03 sec
Dow UCAR (EG) ADF	50/50	4 min 20 sec
Dow XL-54	As received	4 min 42 sec

TABLE 3. BROOKFIELD VISCOSITY (*) (mPa•s)

Fluid Dilution	Temp (°C)	0.3 rpm Viscosity	0.3 rpm Accuracy	6 rpm Viscosity	6 rpm Accuracy	30 rpm Viscosity	30 rpm Accuracy
Octagon Octaflo EF	20	< 20	200(1)	8	10(1)	9.2	2(1)
65/35	0	40	200(1)	26	10(1)	27.8	2(1)
Octagon Octaflo EF	20	< 20	200(1)	5	10(1)	5.8	2(1)
50/50	0	< 20	200(1)	14	10(1)	15.2	2(1)
Dow UCAR (PG) ADF	20	< 20	200(1)	8	10(1)	8.6	2(1)
65/35	0	40	200(1)	27	10(1)	26.8	2(1)
Dow UCAR (PF) ADF	20	< 20	200(1)	7	10(1)	6.8	2(1)
50/50	0	< 20	200(1)	17	10(1)	16.2	2(1)
Dow UCAR (EF) ADF	20	< 20	200(1)	4	10(1)	4.0	2(1)
50/50	0	< 20	200(1)	9	10(1)	9.0	2(1)
Dow XL-54	20	< 20	200(1)	4	10(1)	4.8	2(1)
As received	0	< 20	200(1)	10	10(1)	10.0	2(1)

(*) Cylindrical spindle number: * = 1, 2, or 3

2.2 OUTDOOR TEST SETUP.

The setup used for the outdoor testing was located on the roof of the main building at the Université du Québec à Chicoutimi (see figures 1 and 2). It consisted of a support which held two test plates and two snow catch pans (see figure 3). The test plates, as specified in reference 2, were the same as the boxes that were used for the rain on a cold-soaked wing test of the proposed AS5485 [4], with the exception that the plates were not filled with a coolant, thus empty.

Each support consisted of an 43- x 30- x 7.5-cm aluminum box overlain with a 30- x 50-cm test plate made of AMS 4037 aluminum alloy, 3.2 mm (1/8 in.) thick (see figure 4). Each box was contained within a 25-mm-thick polystyrene insulating jacket, equivalent to a thermal resistance of 1.3. Each box was also equipped with a remote temperature detection (RTD) probe embedded into the center of the test plate, 30 cm from the top, and linked to a data acquisition program which recorded the plate temperature throughout each test. All test plates and ice catch pans were inclined at a 10° angle from horizontal.

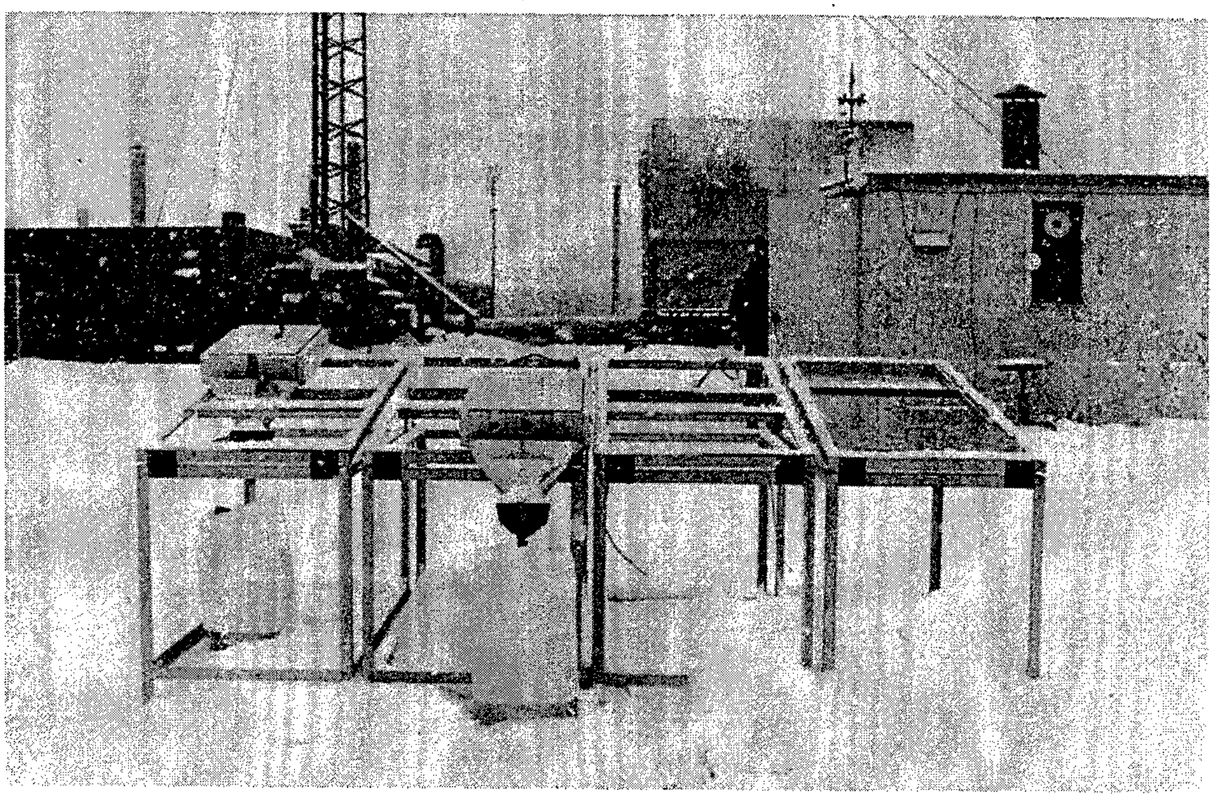


FIGURE 1. OUTDOOR TEST SETUP SUPPORT AND CABIN

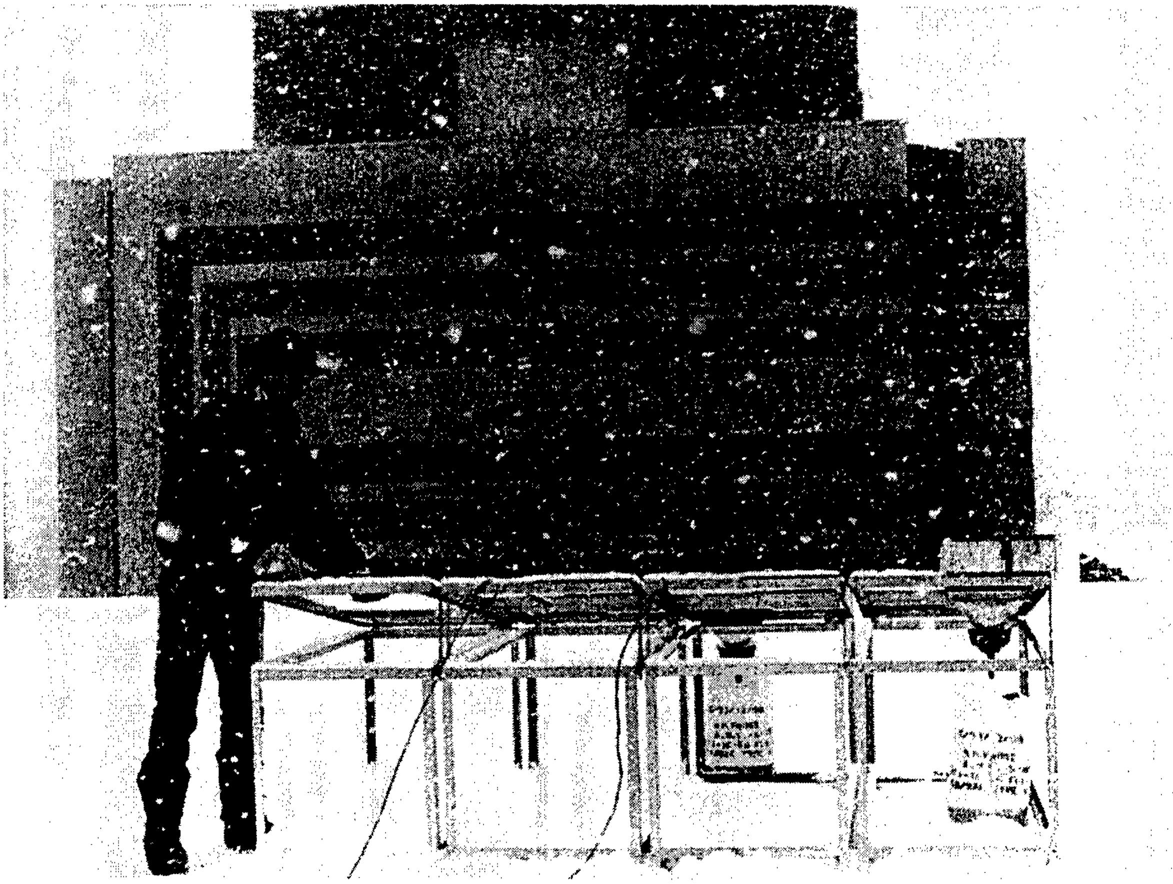


FIGURE 2. OUTDOOR TEST SETUP SUPPORT, VIEW FROM BEHIND

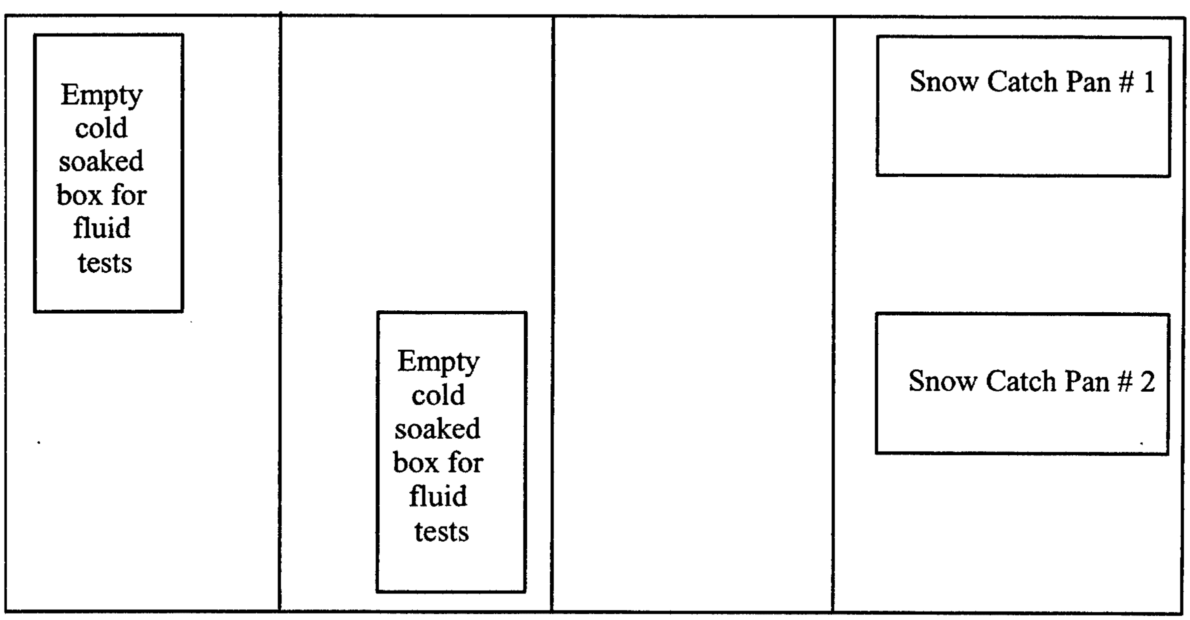


FIGURE 3. TEST PLATE AND SNOW CATCH PLATE LAYOUT ON OUTDOOR TEST PLATE SUPPORT

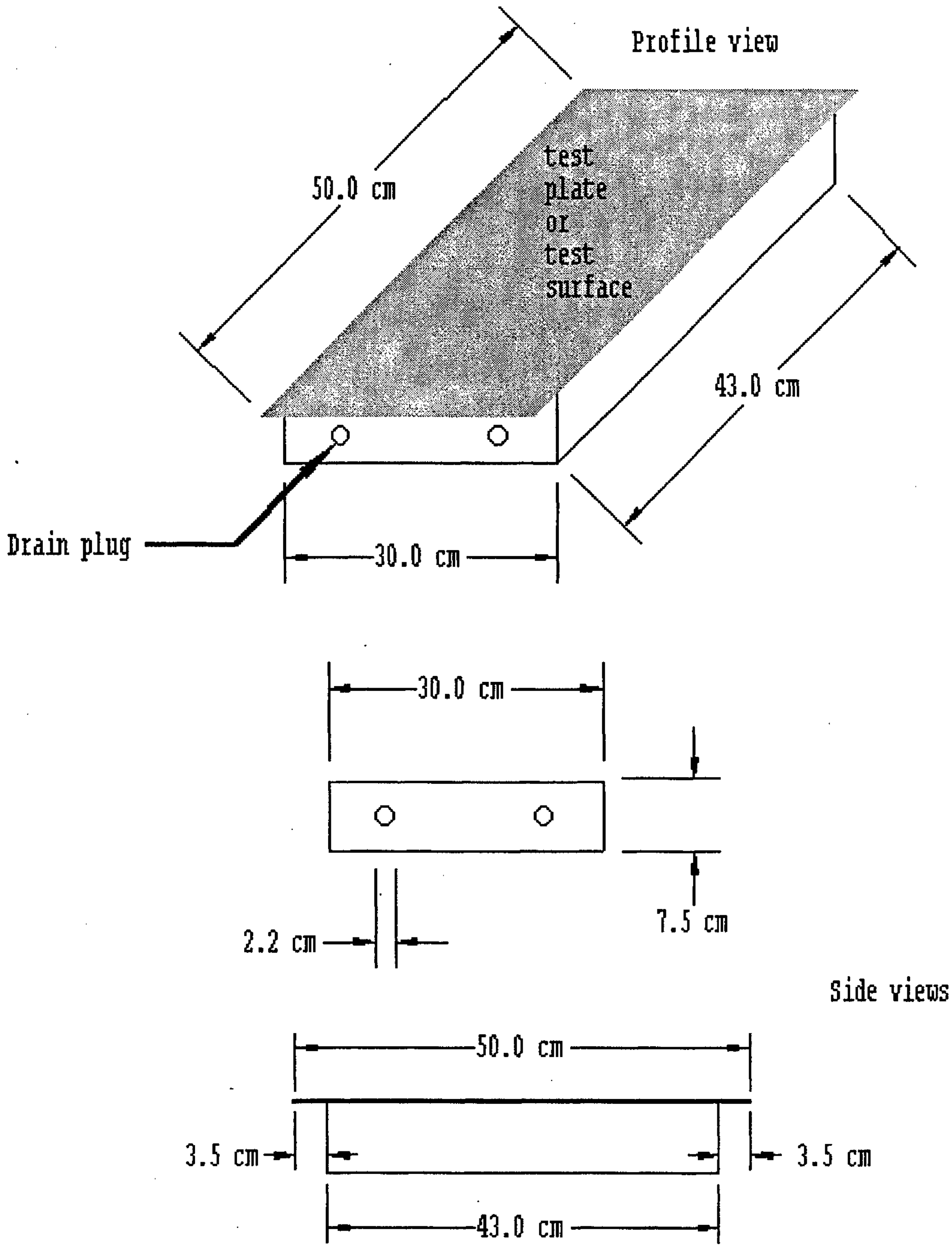


FIGURE 4. THERMAL EQUIVALENT BOX AND TEST PLATE

2.3 TEST PLATE TEMPERATURE PROFILE.

Preliminary tests were conducted to ensure the same test temperature profile was obtained when coated with deicing fluid at 60°C as with the wing leading edge [2]. From the study by APS Aviation [2], an average temperature profile was determined from wing leading edges coated with heated Type I deicing fluids, along with the 1 and 2 sigma variations. The results of this, along with results from the box selected by APS Aviation to be a wing leading edge

thermodynamic equivalent, are presented in figure 5. On the same graph, good correlation of the AMIL thermal equivalent box (see figure 4) to the mean wing leading edge temperature profile is shown.

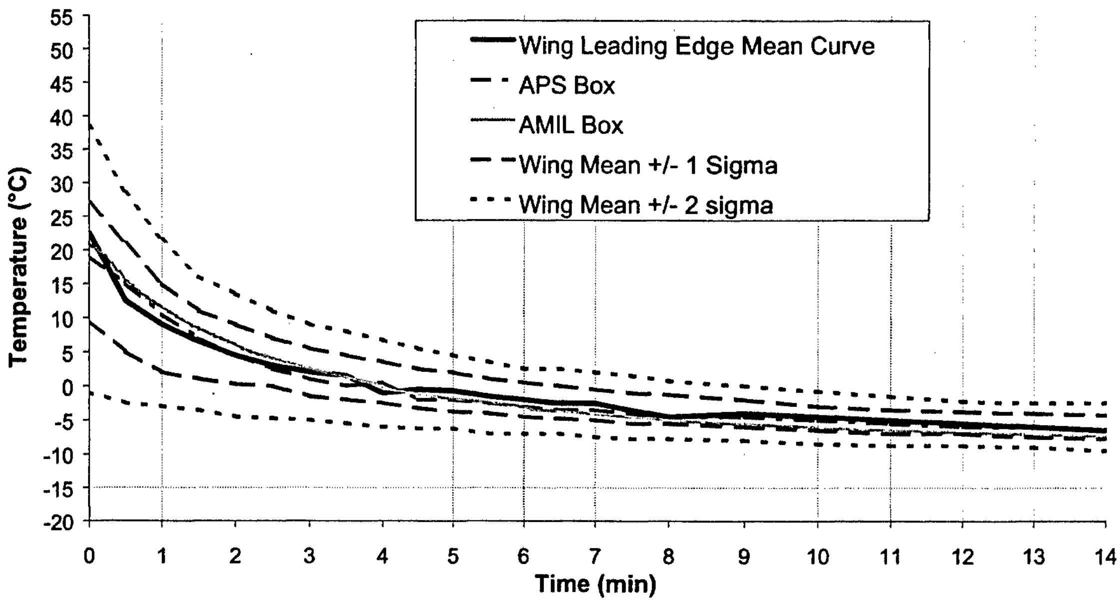


FIGURE 5. TEMPERATURE PROFILES FOR WING LEADING EDGE AND THERMODYNAMIC EQUIVALENT BOXES WITH 0.5 L OF TYPE I FLUID HEATED TO 60°C, NORMALIZED TO -9°C OAT

Two snow catch pans (shown in figure 3) were set to catch the snow alternately. Each pan was first coated with a film of anti-icing fluid and its initial weight recorded. The anti-icing fluid was used to ensure that all falling snow was collected and not blown away from the pan. Each pan was then exposed in rotation for 5 minutes before being covered with a lid. Once the 5 minutes were up, the covered pan was carried into a nearby cabin, weighed again, and then brought back to the test plate support. When the 5 minutes of exposure of the second exposed pan was over, the lid was removed from the first covered pan and placed over the second exposed pan. This procedure was repeated until the failure time was observed.

2.4 OUTDOOR TEST PROCEDURE.

The procedure consisted of:

1. Preparing 500 mL of deicing fluid, diluted to a 10° buffer according to the outside air temperature for the concentrates (Octagon Octaflo EF, Dow UCAR ADF (PG), and Dow UCAR ADF (EG)); the other two fluids (Octagon Octaflo EF Pre-mix and Dow XL-54) were premixes used as received and not further diluted.

2. The fluids were placed in a 600-mL Pyrex lab beaker and heated on a hot plate and were intermittently stirred using a thermometer to at least 60°C.

3. Once the test plate temperature was within 1 degree of the air temperature and the fluid was at least 60°C, the excess snow was removed from the plate, and the fluid was applied to the test plate. A spreader (see figure 6) was used to coat the entire surface of the plate, from top to bottom. The spreader was made from a 30-cm-long ABS pipe with 13 3.7-mm (3/16-in.) -diameter holes drilled into the base 2.3 cm apart.

4. Once the fluid was poured, the timer was started and the time that the plate was covered with 30% snow was recorded.

5. The plate was then cleaned with a squeegee, ethanol, and paper towels. Once cleaned, the temperature of the plate was left to return within 1 degree of the ambient air temperature before beginning another test.

FIGURE 6. FLUID APPLICATION AND SPREADER

3. RESULTS.

3.1 OUTDOOR SNOW EVENTS.

The outdoor tests were run during 18 snow events in Chicoutimi between January and March 2002. A summary of the snow events is presented in table 4.

TABLE 4. OUTDOOR SNOW EVENTS

Test No.	Average Snow Intensity ($g/dm^2/h$)	Average Air Temperature (°C)	Average Wind Speed (m/s)	Wind Direction	Fluid Failures
OS2001	3.8	-3.5	1.9	E	11
OS2002	2.8	-3.5	2.6	SW	8
OS2003	3.7	-9.9	3.3	E	8
OS2004	1.3	-12	1.1	NW	4
OS2005	1.4	-5.5	0.9	W	6
OS2006	3.9	-8.6	3.3	SE	4
OS2007	3.6	-7.0	2.2	SE then S	14
OS2008	9.8	-4.4	0.8	SE	8
OS2009	1.9	-9.9	0.6	SW	4
OS2010	1.9	-11.1	2.8	SW then W	4
OS2011	3.6	-11.7	4.2	E then SE	10
OS2012	3.9	-14.6	6.9	E	8
OS2013	9.4	-14.6	6.9	E then W	2
OS2015	9.2	-8.1	2.7	NE	30
OS2016	3.5	-8.9	3.3	E	12
OS2017	3.8	-7.7	3.1	NE	2
OS2018	10.1	-10.9	5.6	NE	20
OS2019	13.5	-11.9	6.7	E	36
Average	5.1	-9.0	3.3	-	-

For the 18 snow events, 191 fluid failures were recorded. The average snowfall rate varied between 1.3 and 13.5 $g/dm^2/h$, with an average of 5.1 $g/dm^2/h$. However, higher intensities were observed for individual fluid tests during an event. The air temperature for these tests ranged from -3.5° to -14.6°C, with an average of -9.0°C. The wind speed varied from 0.0 to 6.9 m/s, with an average of 3.3 m/s for the 18 snow events. Tests could not be conducted under conditions where wind speeds exceeded 8 m/s; high wind speed made it impossible to measure the rates because the fluid and snow would not stay on the test plates or in the snow catch pans.

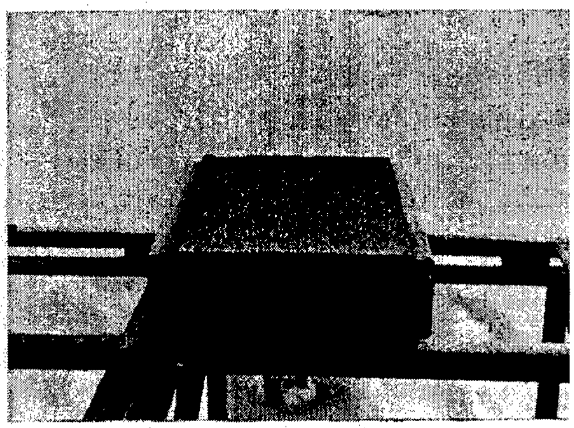
For the 18 snow events, eight crystal types were observed: stellar crystals, irregular crystals, spatial dendrites, plates, columns, capped columns, needles, and soft hail (see table 5). However, for most tests, the crystals consisted of a mix of stellar crystals and spatial dendrites. Their sizes varied from 0.2 to 5.0 mm.

TABLE 5. OUTDOOR TEST SNOW CRYSTALS

Test No.	Crystal Type	Size
OS2001	stellar crystals spatial dendrites	< 1 mm
OS2002	spatial dendrites	4 mm
OS2003	stellar crystals spatial dendrites	< 1 mm
OS2004	stellar crystals spatial dendrites	< 1 mm
OS2005	spatial dendrites	1 to 5 mm
OS2006	spatial dendrites	< 1 mm
OS2007	spatial dendrites	< 1 mm
OS2008	stellar crystals spatial dendrites	< 1 mm
OS2009	spatial dendrites	< 1 mm
OS2010	spatial dendrites	< 1 mm
OS2011	stellar crystals spatial dendrites	< 1-mm clusters
OS2012	Plates Columns stellar crystals spatial dendrites	1 to 3 mm
OS2013	stellar crystals spatial dendrites	< 1 mm
OS2015	stellar crystals spatial dendrites	< 1-mm clusters
OS2016	stellar crystals spatial dendrites	< 1 mm
OS2017	stellar crystals spatial dendrites	clusters up to 1 cm
OS2018	stellar crystals spatial dendrites	< 1 mm
OS2019	stellar crystals spatial dendrites	2 mm

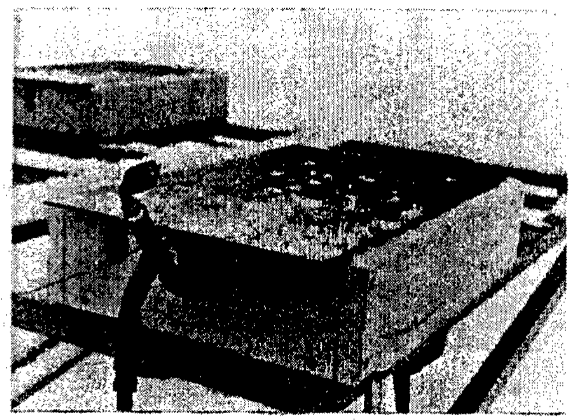
Figure 7 shows two typical fluid failures observed during outdoor snow tests. In both cases, fluid failure started from the top. In the first case, the snow consisted of fine crystals at a -7.7°C temperature, in the second, larger crystals at -4.5°C.

12.08 g/dm^{2}h at -7.7°C
Octaflo EF (PG) 40/60
Outdoor Snow Test



OS2015 (2) probe #7: 7 min 05 sec

8.43 g/dm^{2}h at -4.5°C
Octaflo EF (PG) 35/65
Outdoor Snow Test



OS2005 (2) probe #8: Snow Failure 11 min 55 sec

FIGURE 7. TWO TYPICAL FLUID FAILURES

3.2 FLUID TESTS.

3.2.1 Octagon Octaflo EF.

Thirty-six tests were successfully performed on Octagon Octaflo EF. The results are presented in table 6. A graph comparing snowfall rates and anti-icing endurance times is presented in figure 8. All tests were conducted within an outside temperature range of -3° to -12°C. Octagon Octaflo EF was diluted according to manufacturer recommendations. The dilutions used for these tests are summarized in table 7.

Figure 8 shows that the anti-icing endurance time decreases as the snowfall rate increases. Since the position of the dots on the graph suggests that the anti-icing endurance time can be expressed as a negative power function of the snow rate, a regression analysis was performed.

A mathematical regression analysis of the data was done using the equation:

$$t = aI^{-b} \quad (1)$$

where:

t = anti-icing endurance time
I = snow intensity
a, b = constants determined for each fluid and temperature interval

TABLE 6. OUTDOOR SNOW TEST RESULTS FOR OCTAGON OCTAFLO EF

Test No.	Dilution (% fluid/% water)	Air Temperature (°C)	Intensity (g/dm²/h)	Wind Speed (km/h)	Fluid Endurance Time
OS2001(4)	35/65	-3.6 ±0.03	3.95	5 to 9	14 min 15 sec
OS2002(4)	35/65	-3.7 ±0.06	1.94	13	23 min 15 sec
OS2002(4)	35/65	-3.7 ±0.05	2.02	13	20 min 52 sec
OS2001(4)	35/65	-3.7 ±0.03	3.47	5 to 9	14 min 55 sec
OS2005(2)	35/65	-4.5 ±0.71	8.43	0	11 min 55 sec
OS2005(2)	35/65	-4.5 ±0.71	8.43	0	11 min 55 sec
OS2008(2)	35/65	-4.5 ±0.03	15.60	0 to 5	7 min 44 sec
OS2008(2)	35/65	-4.5 ±0.02	15.60	0 to 5	6 min 30 sec
OS2015(5)	40/60	-6.6 ±0.39	8.12	0 to 8.6	9 min 28 sec
OS2015(5)	40/60	-6.6 ±0.30	8.12	0 to 8.6	9 min 51 sec
OS2007(3)	40/60	-6.8 ±0.04	3.25	10 to 15	12 min 07 sec
OS2015(2)	40/60	-7.6 ±0.06	12.08	0 to 8.6	7 min 12 sec
OS2015(8)	40/60	-7.6 ±0.06	9.04	10 to 15	6 min 10 sec
OS2015(2)	40/60	-7.7 ±0.03	12.08	0 to 8.6	6 min 22 sec
OS2015(8)	40/60	-7.7 ±0.07	11.28	10 to 15	7 min 41 sec
OS2017(1)	40/60	-7.8 ±0.04	3.12	11	16 min 00 sec
OS2017(1)	40/60	-7.8 ±0.03	3.31	11	11 min 07 sec
OS2015(11)	40/60	-8.3 ±0.09	7.96	10 to 15	7 min 28 sec
OS2015(11)	40/60	-8.4 ±0.07	7.96	10 to 15	6 min 54 sec
OS2016(3)	40/60	-9.0	2.98	±16	16 min 20 sec
OS2016(3)	40/60	-9.0	2.98	±16	15 min 50 sec
OS2015(14)	40/60	-9.7 ±0.07	5.08	15 to 20	8 min 34 sec
OS2015(14)	40/60	-9.7 ±0.07	5.08	15 to 20	8 min 47 sec
OS2003(4)	40/60	-10.0 ±0.02	1.15	10 to 15	10 min 46 sec
OS2003(4)	40/60	-10.0 ±0.02	1.15	10 to 15	11 min 40 sec
OS2018(4)	45/55	-10.7 ±0.03	12.72	30	6 min 18 sec
OS2011(1)	45/55	-10.8 ±0.05	4.24	14	13 min 09 sec
OS2011(1)	45/55	-10.8 ±0.06	4.59	14	12 min 15 sec
OS2018(9)	45/55	-11.2 ±0.02	17.96	24 to 40	5 min 47 sec
OS2019(4)	45/55	-11.4 ±0.02	6.44	15 to 25	7 min 43 sec
OS2019(4)	45/55	-11.4 ±0.03	4.28	15 to 25	8 min 02 sec
OS2010(2)	45/55	-11.5 ±0.20	1.00	10	17 min 21 sec
OS2019(9)	45/55	-12.0 ±0.02	22.80	20 to 40	3 min 45 sec
OS2019(9)	45/55	-12.0 ±0.03	22.80	20 to 40	3 min 13 sec
OS2019(14)	45/55	-12.0 ±0.02	23.84	20 to 30	3 min 43 sec
OS2019(14)	45/55	-12.0 ±0.01	25.12	20 to 30	3 min 11 sec

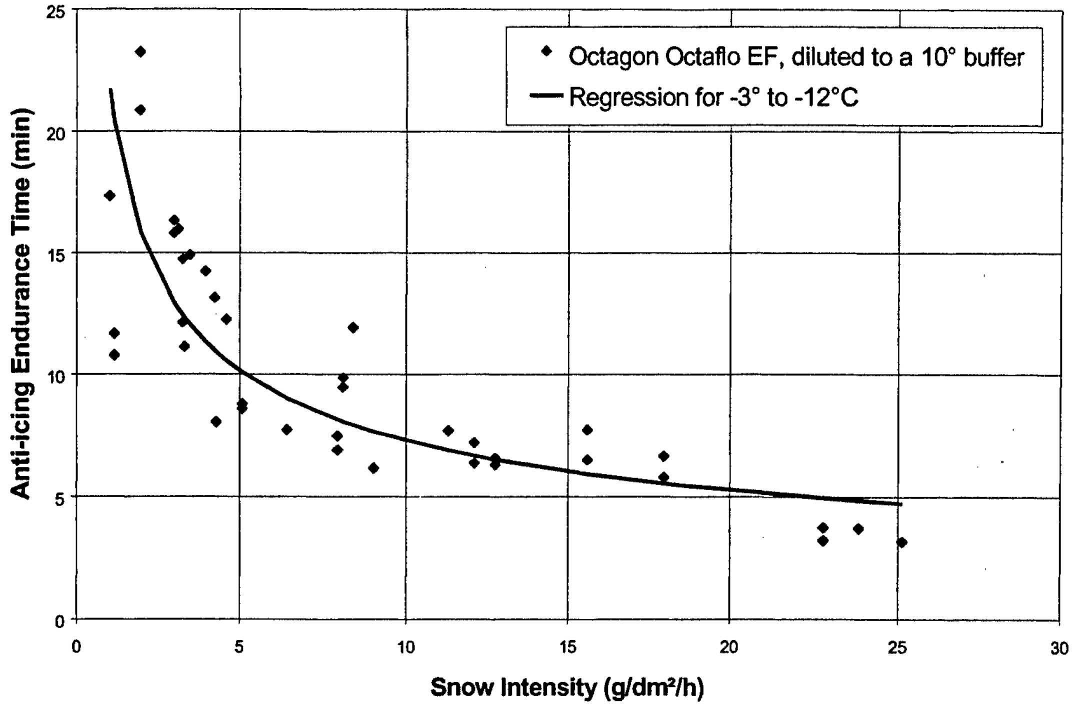


FIGURE 8. ANTI-ICING ENDURANCE TIME VERSUS SNOW INTENSITY FOR OCTAGON OCTAFLO EF

TABLE 7. OCTAGON OCTAFLO EF DILUTION CHART

Air Temperature (°C)	Dilution (Fluid/Water) (ml)
2.0 to -1.9	150/350
-2.0 to -5.9	175/325
-6.0 to -9.9	200/300
-10.0 to -12.9	225/275
-13.0 to -18.9	250/250
-19.0 to -24.9	275/225
-25.0 to -30.9	300/200

3.2.2 Dow UCAR ADF (PG).

Thirty-five tests were successfully performed on Dow UCAR ADF (PG) (see table 8) at outside air temperatures ranging from -3.5° to -14.6°C and snowfall intensities of 0.86 to 23.04 g/dm²/h. The fluids tested were diluted to a 10° buffer, according to the chart in table 9.

A graph comparing snowfall rates and anti-icing endurance times is presented in figure 9. The graph shows that the anti-icing endurance time decreases with increasing snowfall rate. A negative power regression was drawn through the data, using equation 1.

TABLE 8. OUTDOOR SNOW TEST RESULTS FOR DOW UCAR ADF (PG)

Test No.	Fluid	Dilution (% fluid/% water)	T_{air} (°C)	Intensity (g/dm^2h)	Wind Speed (km/h)	Fluid Endurance Time
OS2001(3)	E382	33/67	-3.5 ±0.03	3.71	5 to 9	14 min 37 sec
OS2001(3)	E382	33/67	-3.5 ±0.03	3.72	5 tp 9	16 min 05 sec
OS2002(3)	E382	33/67	-3.6 ±0.08	2.46	5	19 min 46 sec
OS2002(3)	E382	33/67	-3.7 ±0.05	2.44	5	16 min 40 sec
OS2007(2)	E382	38/62	-6.9 ±0.02	4.67	10 to 15	10 min 18 sec
OS2007(7)	E382	38/62	-7.3 ±0.03	1.98	0 to 5	15 min 20 sec
OS2015(6)	E382	38/62	-7.4 ±0.07	8.08	5 to 10	6 min 34 sec
OS2015(6)	E382	38/62	-7.4 ±0.05	8.08	5 to 10	7 min 45 sec
OS2015(3)	E382	38/62	-7.5 ±0.02	16.20	0 to 8.6	6 min 23 sec
OS2015(3)	E382	38/62	-7.5 ±0.02	13.56	0 to 8.6	5 min 56 sec
OS2015(9)	E382	38/62	-7.6 ±0.13	10.64	10 to 15	5 min 57 sec
OS2015(9)	E382	38/62	-7.6 ±0.14	10.64	10 to 15	6 min 10 sec
OS2016(6)	E382	40/60	-8.0	4.15	4	27 min 10 sec
OS2015(12)	E382	40/60	-8.8 ±0.05	5.80	10 to 15	7 min 20 sec
OS2015(12)	E382	40/60	-8.8 ±0.05	5.80	10 to 15	7 min 28 sec
OS2016(2)	E382	40/60	-9.4	0.86	16	20 min 40 sec
OS2016(2)	E382	40/60	-9.4	1.20	16	20 min 45 sec
OS2009(2)	E382	42.5/57.5	-9.7 ±0.52	0.86	0 to 3	17 min 34 sec
OS2009(2)	E382	42.5/57.5	-9.7 ±0.49	1.00	0 to 3	19 min 35 sec
OS2003(3)	E382	40/60	-10.0 ±0.04	3.07	10 to 15	10 min 40 sec
OS2003(3)	E382	40/60	-10.0 ±0.05	3.07	10 to 15	10 min 52 sec
OS2015(15)	E382	40/60	-10.2 ±0.03	2.53	15 to 20	12 min 52 sec
OS2015(15)	E382	40/60	-10.2 ±0.04	2.40	15 to 20	14 min 30 sec
OS2011(5)	E382	42.5/57.5	-10.7 ±0.06	1.47	13 to 14	10 min 42 sec
OS2018(3)	E382	42.5/57.5	-10.9 ±0.25	4.92	10 to 15	8 min 55 sec
OS2018(8)	E382	42.5/57.5	-11.1 ±0.04	3.28	16 to 22	10 min 49 sec
OS2019(3)	E382	42.5/57.5	-11.2 ±0.04	9.64	15	5 min 50 sec
OS2019(3)	E382	42.5/57.5	-11.2 ±0.04	9.64	15	5 min 39 sec
OS2019(18)	E382	42.5/57.5	-11.6 ±0.02	4.52	20 to 30	6 min 33 sec
OS2019(18)	E382	42.5/57.5	-11.6 ±0.02	4.52	20 to 30	5 min 25 sec
OS2019(13)	E382	45/55	-11.9 ±0.01	23.04	20 to 30	3 min 10 sec
OS2019(13)	E382	45/55	-11.9 ±0.01	23.04	20 to 30	2 min 52 sec
OS2019(8)	E382	42.5/57.5	-12.0 ±0.01	13.28	20 to 25	4 min 02 sec
OS2012(2)	E382	46.5/53.5	-14.6 ±0.08	5.12	20 to 30	6 min 40 sec
OS2012(2)	E382	46.5/53.5	-14.6 ±0.06	5.08	20 to 30	6 min 43 sec

TABLE 9. DOW UCAR ADF (PG) DILUTION CHART

Air Temperature (°C)	Dilution (Fluid/Water) (ml)
2.0 to 0.1	125/375
0.0 to -1.9	145/355
-2.0 to -3.9	165/335
-4.0 to -5.9	177/323
-6.0 to -7.9	190/310
-8.0 to -9.9	200/300
-10.0 to -11.9	212/288
-12.0 to -13.9	225/275
-14.0 to -15.9	233/267
-16.0 to -17.9	242/258
-18.0 to -19.9	250/250
-20.0 to -21.9	255/245
-22.0 to -23.9	268/232
-24.0 to -25.9	270/230

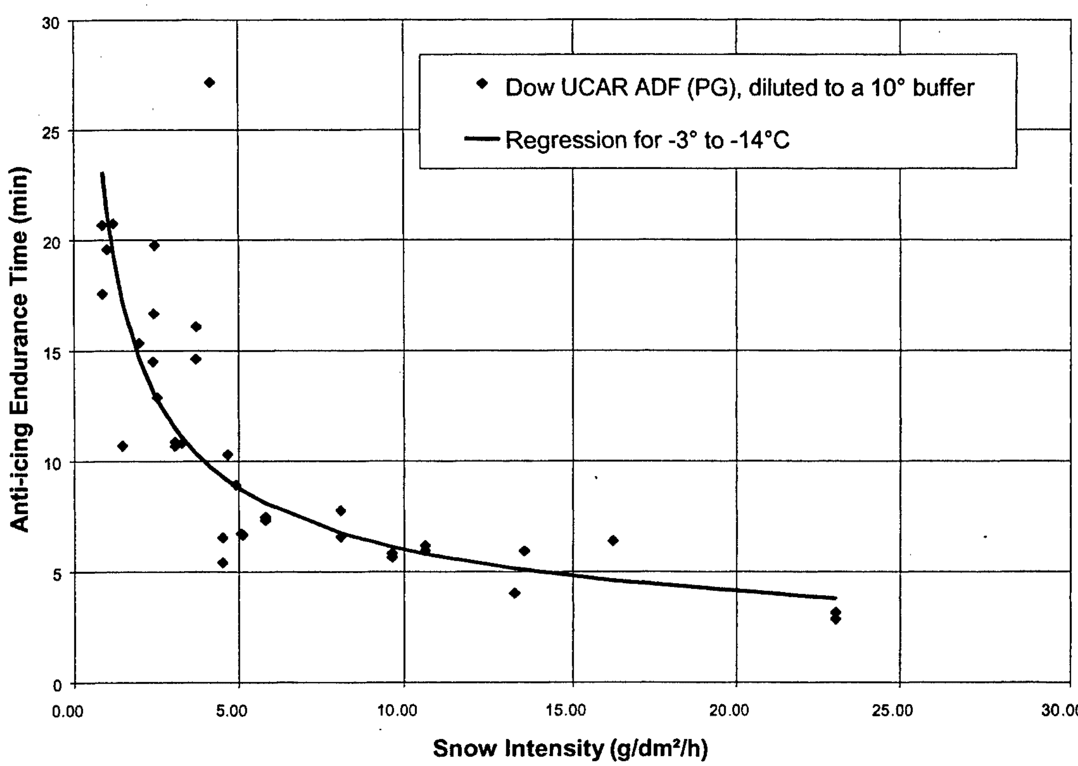


FIGURE 9. ANTI-ICING ENDURANCE TIME VERSUS SNOW INTENSITY FOR DOW UCAR ADF (PG)

3.2.3 Dow UCAR ADF (EG).

Thirty-one tests were successfully performed on Dow UCAR ADF (EG) (see table 10) at outside air temperatures ranging from -3.4° to -15.1°C and snowfall intensities ranging from 1.20 to 27.20 g/dm²/h. The fluids were diluted to a 10° buffer to the outside air temperature, according to the chart in table 11.

TABLE 10. OUTDOOR SNOW TEST RESULTS FOR DOW UCAR ADF (EG)

Test No.	Fluid	Dilution (Fluid/Water)	T_{air} (°C)	Intensity (g/dm^2h)	Wind Speed (km/h)	Fluid Endurance Time
OS2001(2)	E143	27.5/72.5	-3.4 ±0.04	5.07	5 to 9	14 min 00 sec
OS2001(2)	E143	27.5/72.5	-3.5 ±0.03	4.93	5 to 9	12 min 07 sec
OS2001(6)	E143	27.5/72.5	-3.8 ±0.01	1.20	7	28 min 53 sec
OS2002(2)	E143	26/74	-3.4 ±0.10	2.66	5	16 min 14 sec
OS2002(2)	E143	26/74	-3.4 ±0.08	2.66	5	18 min 02 sec
OS2003(2)	E143	35/65	-9.9 ±0.03	5.04	10 to 15	7 min 55 sec
OS2003(2)	E143	35/65	-9.9 ±0.03	4.44	10 to 15	6 min 44 sec
OS2005(3)	E143	27.5/72.5	-5.8 ±0.15	4.94	0 to 1	16 min 00 sec
OS2005(3)	E143	27.5/72.5	-5.8 ±0.16	4.94	0 to 1	16 min 00 sec
OS2007(1)	E143	31.5/68.5	-6.9 ±0.03	3.76	10 to 15	12 min 34 sec
OS2007(6)	E143	32.8/67.2	-7.1 ±0.03	4.16	0 to 5	11 min 00 sec
OS2009(1)	E143	36.5/63.5	-10.6 ±0.28	3.63	0 to 3	13 min 52 sec
OS2009(1)	E143	36.5/63.5	-10.6 ±0.28	3.63	0 to 3	13 min 45 sec
OS2011(4)	E143	36.5/63.5	-10.7 ±0.06	2.27	13 to 14	12 min 08 sec
OS2011(4)	E143	36.5/63.5	-10.7 ±0.06	5.36	13 to 14	9 min 19 sec
OS2012(3)	E143	40.5/59.5	-14.7 ±0.03	2.61	20 to 30	14 min 00 sec
OS2012(3)	E143	40.5/59.5	-14.7 ±0.03	2.61	20 to 30	12 min 43 sec
OS2013(1)	E143	40.5/59.5	-14.7 ±0.21	10.24	20 to 30	7 min 25 sec
OS2013(1)	E143	40.5/59.5	-15.1 ±0.09	9.20	20 to 30	10 min 25 sec
OS2016(1)	E143	35.2/64.8	-9.3	6.00	16	12 min 00 sec
OS2016(1)	E143	35.2/64.8	-9.3	3.37	16	27 min 32 sec
OS2016(5)	E143	34/66	-8.7	4.88	4	8 min 10 sec
OS2016(5)	E143	34/66	-8.7	7.40	4	6 min 12 sec
OS2018(2)	E143	36.5/63.5	-10.9 ±0.11	4.69	10	10 min 10 sec
OS2018(7)	E143	36.5/63.5	-10.8 ±0.05	6.92	16 to 22	6 min 15 sec
OS2019(2)	E143	36.5/63.5	-10.8 ±0.08	8.00	15 to 25	7 min 42 sec
OS2019(2)	E143	36.5/63.5	-10.9 ±0.11	8.00	15 to 25	8 min 13 sec
OS2019(7)	E143	37.5/62.5	-11.8 ±0.04	14.00	20 to 25	5 min 20 sec
OS2019(7)	E143	37.5/62.5	-11.9 ±0.04	12.72	20 to 25	4 min 55 sec
OS2019(12)	E143	37.5/62.5	-11.9 ±0.03	27.20	20 to 36	2 min 50 sec
OS2019(17)	E143	37.5/62.5	-11.7 ±0.02	17.76	20 to 30	4 min 18 sec

TABLE 11. DOW UCAR ADF (EG) DILUTION CHART

Air Temperature (°C)	Dilution (Fluid/Water) (ml)
0.0 to -0.9	113/387
-1.0 to -1.9	122/378
-2.0 to -2.9	130/370
-3.0 to -3.9	137/363
-4.0 to -4.9	144/356
-5.0 to -5.9	151/349
-6.0 to -6.9	158/342
-7.0 to -7.9	164/336
-8.0 to -8.9	170/330
-9.0 to -9.9	176/324
-10.0 to -10.9	182/318
-11.0 to -11.9	187/313
-12.0 to -12.9	193/307
-13.0 to -13.9	198/302
-14.0 to -14.9	203/297
-15.0 to -15.9	208/292
-16.0 to -16.9	212/288
-17.0 to -17.9	217/283
-18.0 to -18.9	221/279
-19.0 to -19.9	226/274
-20.0 to -20.9	230/270
-21.0 to -21.9	235/265
-22.0 to -22.9	239/261
-23.0 to -23.9	243/257
-24.0 to -24.9	247/253
-25.0 to -25.9	252/248

A graph comparing snowfall rates and anti-icing endurance times is presented in figure 10. The graph shows that the anti-icing endurance time decreases with increasing snowfall rate. A negative power regression was drawn through the data, using equation 1.

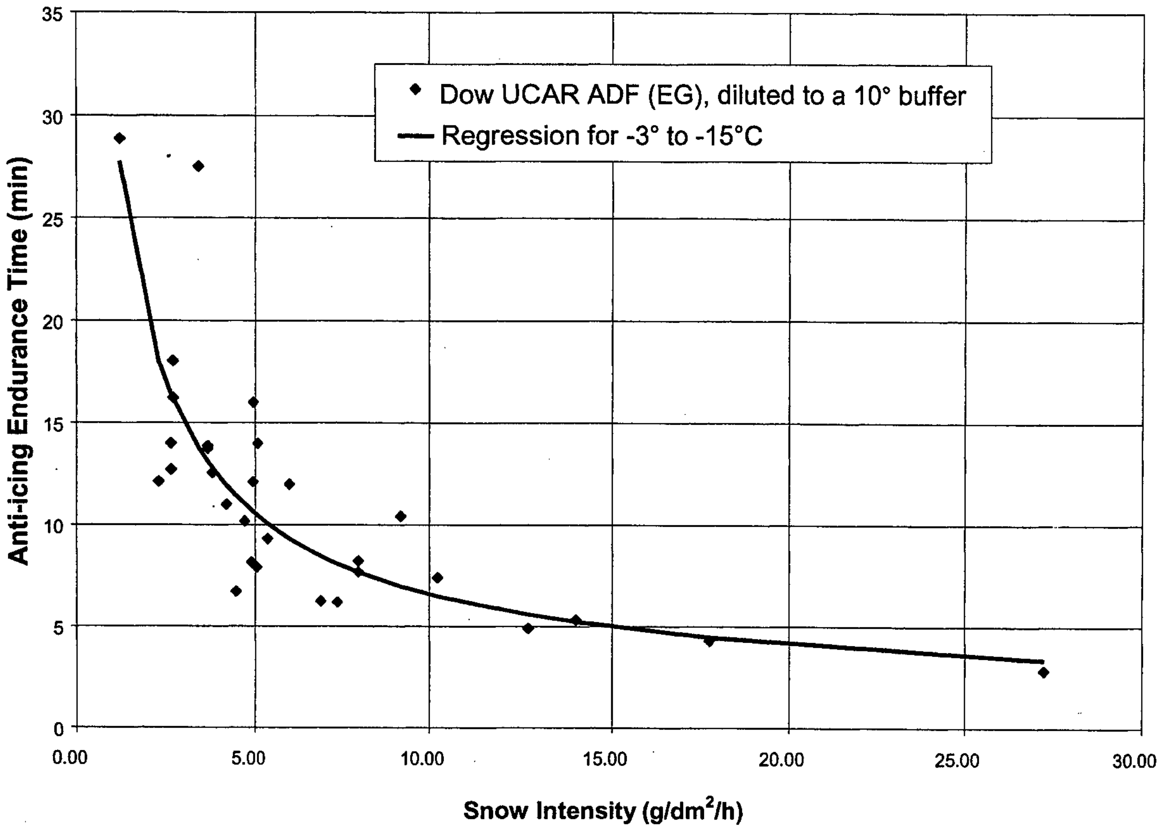


FIGURE 10. ANTI-ICING ENDURANCE TIME VERSUS SNOW INTENSITY FOR DOW UCAR ADF (EG)

3.2.4 Octagon Octaflo EF Pre-mix 55/45.

Twenty-seven tests were successfully performed on Octagon Octaflo EF Pre-mix 55/45 (see table 12), at outside air temperatures ranging from -4.5° to -14.6°C and snowfall intensities of 1.74 to 19.44 g/dm²/h. The fluids were tested in their premix form, without further dilution.

A graph comparing snowfall rates and anti-icing endurance times is presented in figure 11. The graph shows that the anti-icing endurance time decreases with increasing snowfall rate, but with more variation in anti-icing endurance time at lower rates than the fluids diluted to a 10° buffer with the outside air temperature. A negative power regression was drawn through the data, using equation 1.

TABLE 12. OUTDOOR SNOW TEST RESULTS FOR OCTAGON OCTAFLO EF PRE-MIX 55/45

Test	Fluid	Dilution (Fluid/Water)	T_{air} (°C)	Intensity (g/dm^2h)	Wind Speed (km/h)	Fluid Endurance Time
OS2003(1)	E509	------	-9.8 ±0.03	5.65	10 to 15	11 min 40 sec
OS2003(1)	E509	------	-9.8 ±0.03	5.65	10 to 15	10 min 24 sec
OS2004(1)	E509	------	-10.5	1.84	2	14 min 07 sec
OS2004(1)	E509	------	-10.5	1.97	2	14 min 32 sec
OS2006(2)	E509	------	-8.4 ±0.18	2.11	9 to 15	29 min 40 sec
OS2006(2)	E509	------	-8.4 ±0.14	2.40	9 to 15	23 min 25 sec
OS2007(4)	E509	------	-7.0 ±0.05	4.64	10 to 15	12 min 50 sec
OS2008(1)	E509	------	-4.4 ±0.01	18.04	0 to 5	7 min 45 sec
OS2008(1)	E509	------	-4.5 ±0.02	18.04	0 to 5	6 min 42 sec
OS2010(1)	E509	------	-10.8 ±0.35	2.21	10	13 min 50 sec
OS2010(1)	E509	------	-11.0 ±0.32	1.74	10	16 min 31 sec
OS2011(2)	E509	------	-10.7 ±0.08	2.23	14	28 min 37 sec
OS2011(2)	E509	------	-10.8 ±0.05	2.01	14	26 min 00 sec
OS2012(1)	E509	------	-14.4 ±0.07	5.40	20 to 30	8 min 35 sec
OS2012(1)	E509	------	-14.4 ±0.06	5.40	20 to 30	8 min 14 sec
OS2012(4)	E509	------	-14.6 ±0.03	2.43	20 to 30	10 min 02 sec
OS2012(4)	E509	------	-14.6 ±0.03	2.24	20 to 30	6 min 55 sec
OS2018(1)	E509	------	-10.5 ±0.07	8.04	10	9 min 39 sec
OS2018(6)	E509	------	-10.6 ±0.02	9.72	16 to 22	6 min 00 sec
OS2019(1)	E509	------	-10.6 ±0.04	9.88	16.5 to 23	9 min 35 sec
OS2019(1)	E509	------	-10.6 ±0.05	9.88	16.5 to 23	8 min 52 sec
OS2019(6)	E509	------	-11.7 ±0.05	6.36	20 to 22	8 min 45 sec
OS2019(6)	E509	------	-11.7 ±0.04	6.36	20 to 22	7 min 36 sec
OS2019(11)	E509	------	-11.9 ±0.02	9.25	28 to 36	10 min 10 sec
OS2019(11)	E509	------	-11.9 ±0.02	11.04	28 to 36	8 min 37 sec
OS2019(16)	E509	------	-11.8 ±0.02	19.44	20 to 30	5 min 03 sec
OS2019(16)	E509	------	-11.7 ±0.02	19.44	20 to 30	4 min 18 sec

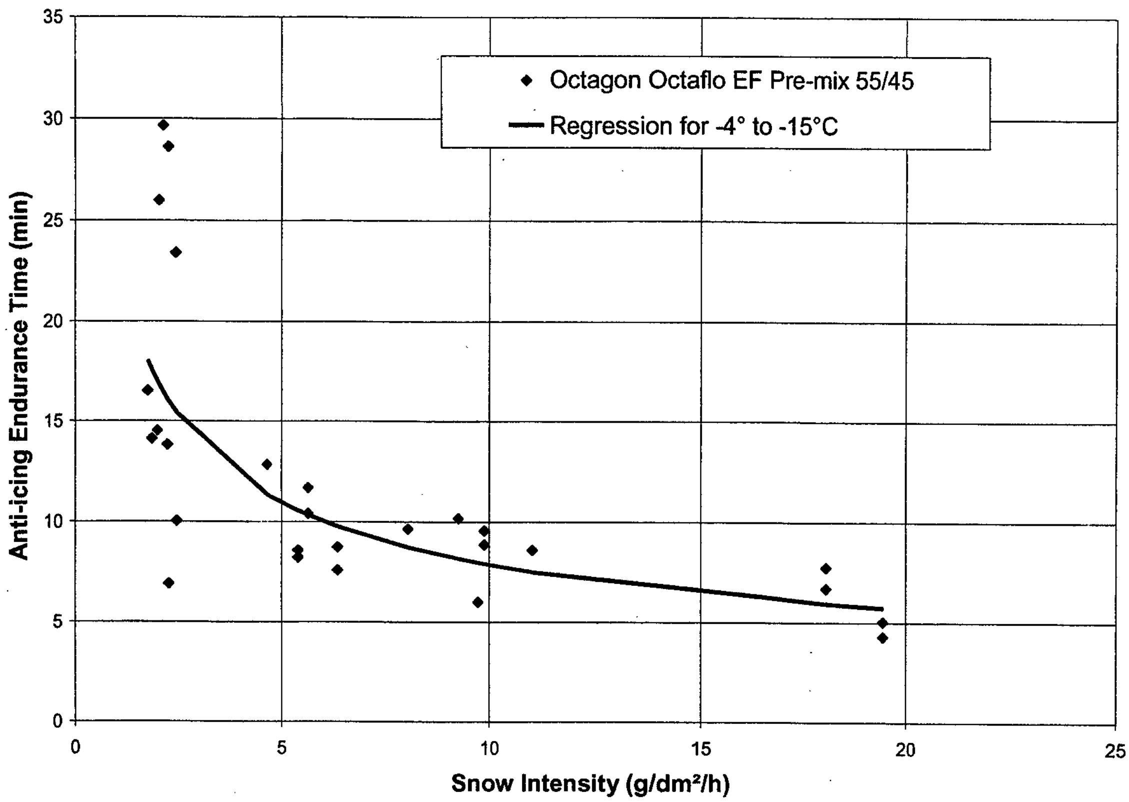


FIGURE 11. ANTI-ICING ENDURANCE TIME VERSUS SNOW INTENSITY FOR OCTAGON OCTAFLO EF PRE-MIX 55/45

3.2.5 Dow XL-54.

Thirty-four tests were successfully performed on Dow XL-54 (see table 13) at outside air temperatures ranging from -3.1° to -11.9°C and snowfall intensities in the range of 0.80 to 22.56 g/dm²/h. Since this fluid is a ready-to-use premix, it was tested without further dilution.

TABLE 13. OUTDOOR SNOW TEST RESULTS FOR DOW XL-54

Test	Fluid	Dilution (Fluid/Water)	T_{air} (°C)	Intensity (g/dm^2h)	Wind Speed (km/h)	Fluid Endurance Time
OS2001(1)	E165	------	-3.2 ±0.14	6.42	5 to 9	16 min 10 sec
OS2001(1)	E165	------	-3.3 ±0.06	6.13	5 to 9	13 min 55 sec
OS2001(5)	E165	------	-3.7 ±0.04	3.39	7	21 min 25 sec
OS2001(5)	E165	------	-3.7 ±0.04	1.95	7	25 min 51 sec
OS2002(1)	E165	------	-3.1 ±0.14	4.05	5	15 min 00 sec
OS2002(1)	E165	------	-3.1 ±0.15	4.00	5	17 min 13 sec
OS2004(2)	E165	------	-13.0	0.80	7	28 min 04 sec
OS2006(1)	E165	------	-8.9 ±0.09	5.63	9 to 15	14 min 28 sec
OS2006(1)	E165	------	-8.9 ±0.08	5.63	9 to 15	12 min 45 sec
OS2007(5)	E165	------	-7.1 ±0.01	4.45	0 to 5	13 min 00 sec
OS2008(3)	E165	------	-4.4 ±0.04	1.80	0 to 5	27 min 10 sec
OS2008(3)	E165	------	-4.4 ±0.04	1.80	0 to 5	26 min 22 sec
OS2011(3)	E165	------	-10.8 ±0.06	8.08	20	10 min 00 sec
OS2011(3)	E165	------	-10.8 ±0.08	6.20	20	15 min 12 sec
OS2015(1)	E165	------	-7.8 ±0.02	22.56	0 to 8.6	4 min 42 sec
OS2015(1)	E165	------	-7.8 ±0.01	22.56	0 to 8.6	4 min 57 sec
OS2015(4)	E165	------	-7.4 ±0.02	11.48	0 to 8.6	8 min 19 sec
OS2015(4)	E165	------	-7.4 ±0.02	11.48	0 to 8.6	7 min 47 sec
OS2015(7)	E165	------	-7.6 ±0.08	9.04	5 to 10	7 min 30 sec
OS2015(7)	E165	------	-7.6 ±0.07	9.04	5 to 10	8 min 43 sec
OS2015(10)	E165	------	-8.0 ±0.07	8.08	10 to 15	8 min 30 sec
OS2015(10)	E165	------	-8.0 ±0.06	8.08	10 to 15	7 min 57 sec
OS2015(13)	E165	------	-9.2 ±0.22	9.32	10 to 15	8 min 25 sec
OS2015(13)	E165	------	-9.3 ±0.14	9.32	10 to 15	8 min 19 sec
OS2016(4)	E165	------	-8.8	3.20	16	14 min 50 sec
OS2016(4)	E165	------	-8.8	3.20	16	14 min 30 sec
OS2018(5)	E165	------	-10.4 ±0.02	11.96	16 to 22	6 min 30 sec
OS2018(10)	E165	------	-11.1 ±0.02	11.04	24 to 40	8 min 24 sec
OS2019(5)	E165	------	-11.6 ±0.04	10.64	20 to 22	9 min 15 sec
OS2019(5)	E165	------	-11.6 ±0.03	10.64	20 to 22	9 min 01 sec
OS2019(10)	E165	------	-11.9 ±0.02	10.56	20 to 30	7 min 54 sec
OS2019(10)	E165	------	-11.9 ±0.02	10.56	20 to 30	7 min 14 sec
OS2019(15)	E165	------	-11.8 ±0.02	16.60	20 to 30	9 min 07 sec
OS2019(15)	E165	------	-11.9 ±0.03	10.04	20 to 30	6 min 27 sec

A graph comparing snowfall rates and anti-icing endurance times is presented in figure 12. The graph shows that the anti-icing endurance time decreases with increasing snowfall rate. A negative power regression was drawn through the data, using equation 1.

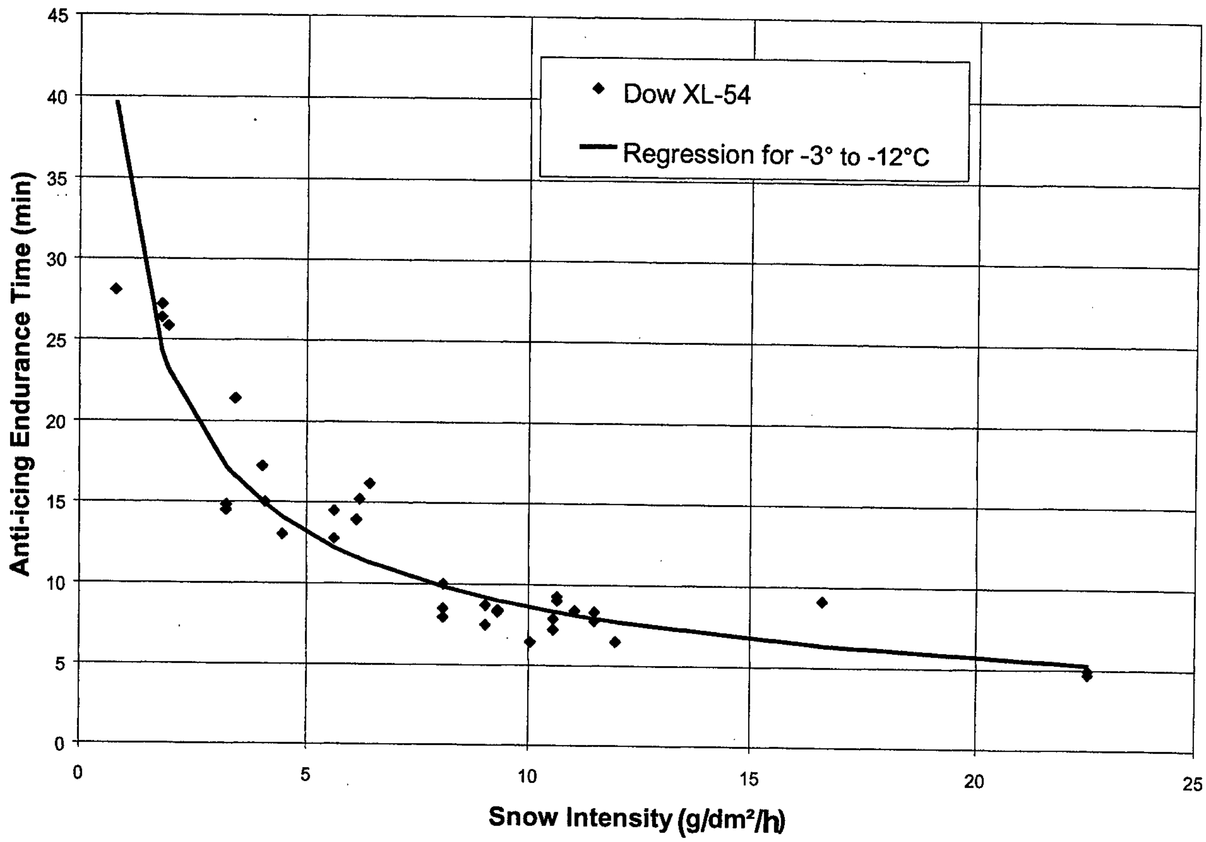


FIGURE 12. ANTI-ICING ENDURANCE TIME VERSUS SNOW INTENSITY FOR DOW XL-54

4. DISCUSSION.

4.1 COMPARISON BETWEEN FLUIDS.

A comparison of anti-icing endurance time versus snow intensity for all fluids is presented in figure 13. Of the fluids tested, there is little clear difference between the fluids, given the scatter of the data. The fluid with the longest times was Octagon Octaflo EF Pre-mix, with a duration about 40% longer than the fluid with the shortest time, Dow UCAR ADF (PG). Figure 14 shows the regression curve and 95% confidence interval for all the data combined.

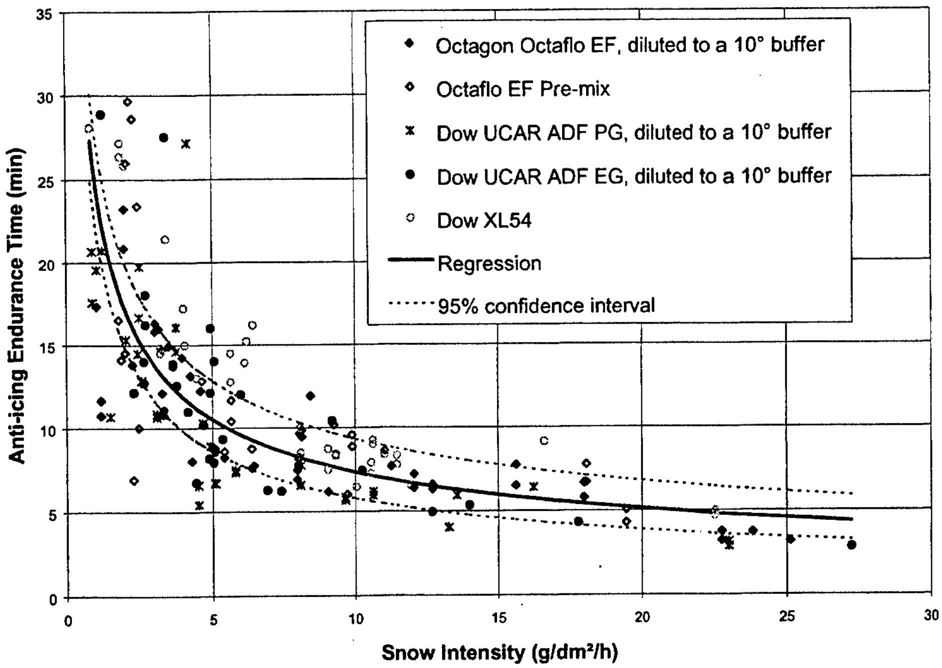


FIGURE 13. ANTI-ICING ENDURANCE TIME VERSUS SNOW INTENSITY FOR ALL FLUIDS

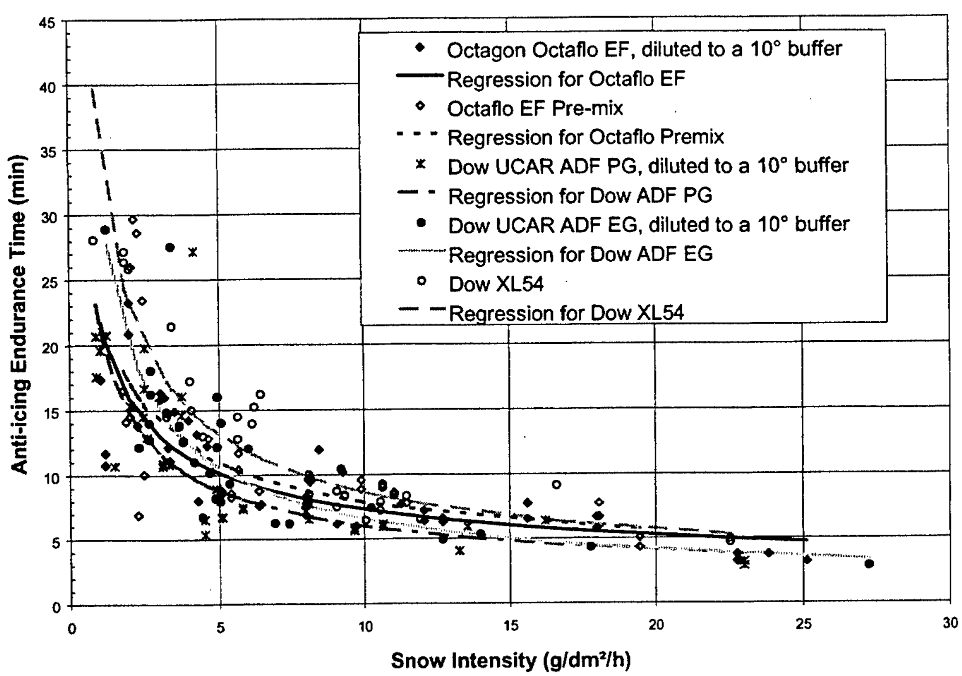


FIGURE 14. ANTI-ICING ENDURANCE TIME VERSUS SNOW INTENSITY FOR ALL FLUIDS WITH CONFIDENCE INTERVALS

4.2 COMPARISON WITH APS AVIATION TEST SITE.

Similar tests were conducted by APS Aviation in Dorval, Quebec, using a similar setup. Their tests were, in general, conducted at higher temperatures. Therefore, the data is compared in the following graphs, according to temperature intervals. Figure 15 shows the data for the above -3°C range. Note that for this temperature interval, no data was obtained at AMIL.

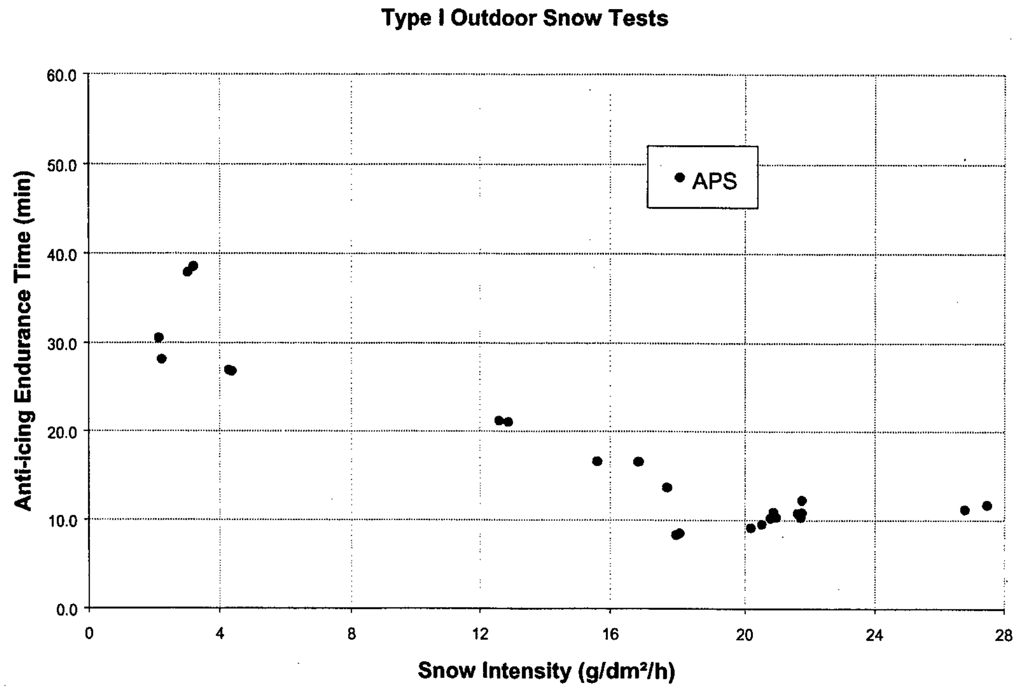


FIGURE 15. OUTDOOR SNOW TESTS AT TEMPERATURES ABOVE -3°C

Figure 16 compares endurance times for the -3° to -10°C temperature range. The graph shows general agreement in the data from the two test sites, but few results from APS Aviation in the high range, above 12 g/dm²/h. Figure 17 shows a comparison for the data between -10° and -25°C. The graph shows a general agreement in the data between the two test sites, with most of the tests in this range obtained at the AMIL site.

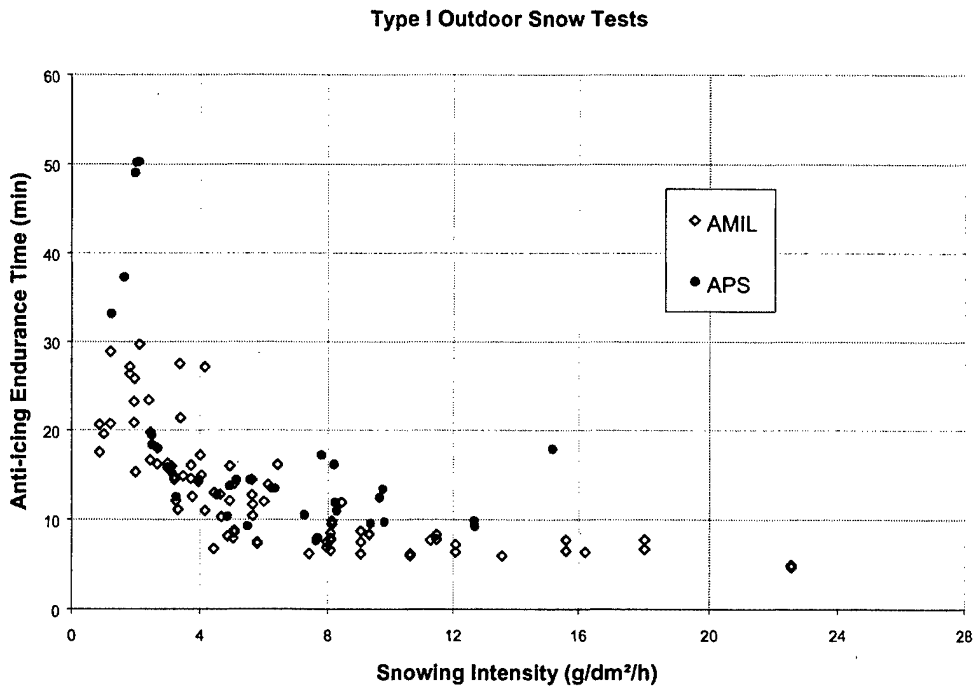


FIGURE 16. OUTDOOR SNOW TESTS AT TEMPERATURES RANGING FROM -3° TO -10°C

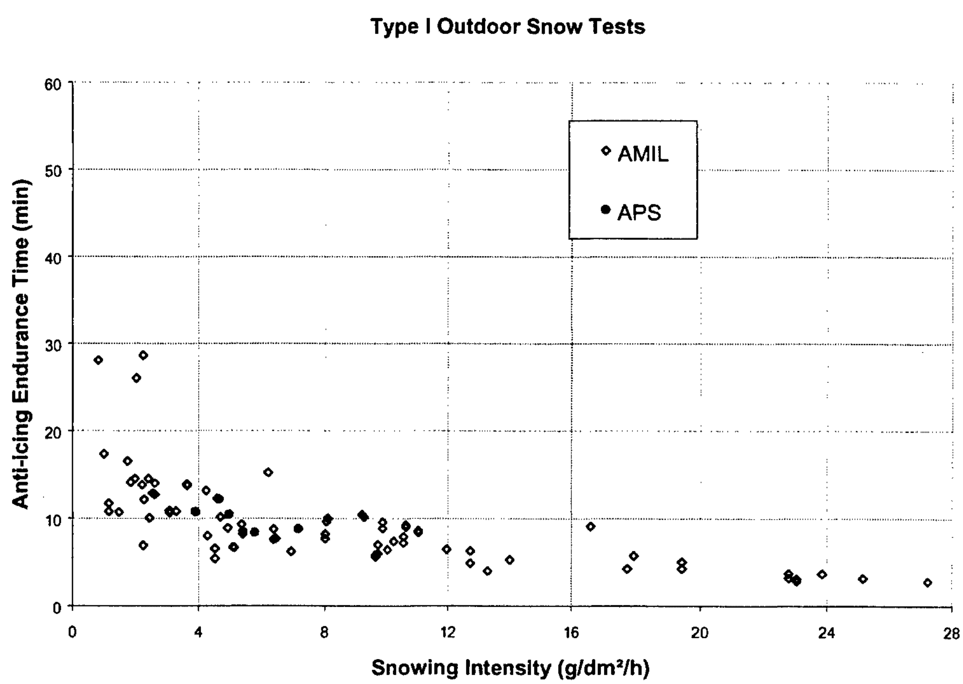


FIGURE 17. OUTDOOR SNOW TESTS AT TEMPERATURES RANGING FROM -10° TO -25°C

4.3 DILUTIONS VERSUS PREMIX.

Figure 18 highlights the differences between the fluids diluted to a 10° buffer and the premix fluids, which in general, are diluted to a freeze point significantly below the 10° buffer. Dow XL-54 has a freeze point of -55°C and Octagon Octaflo EF Pre-mix 55/45, -34°C. The figure shows that slightly longer times, about 20%, were obtained with the premixed fluids.

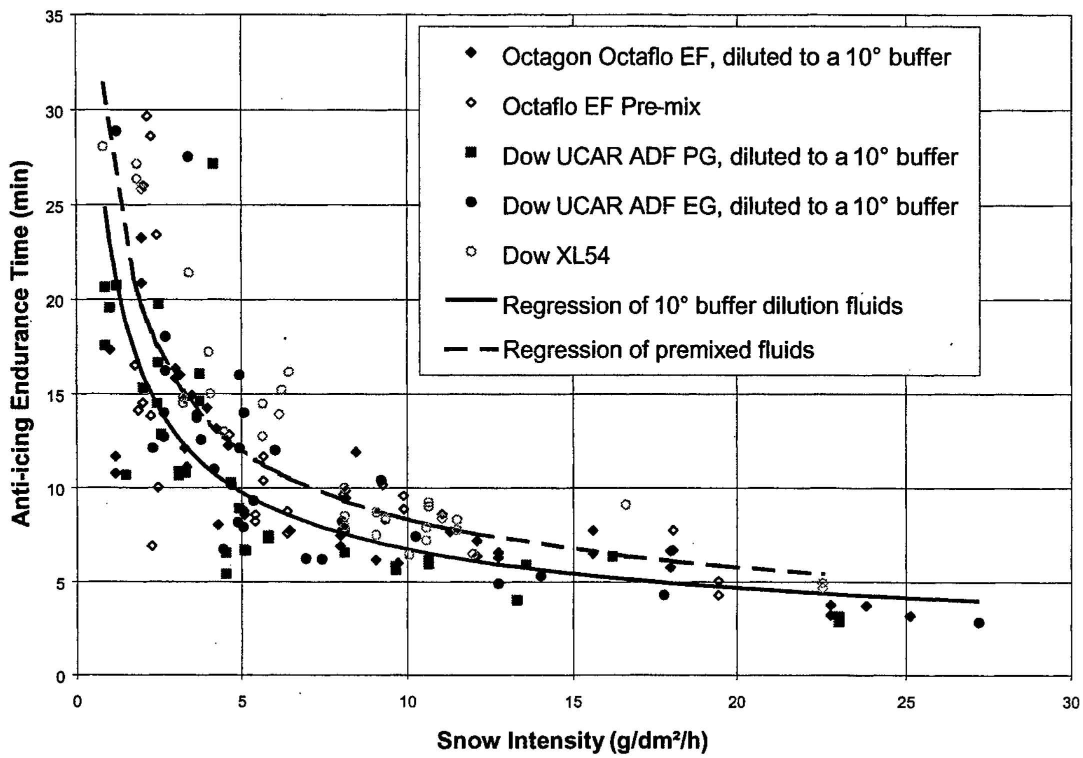


FIGURE 18. COMPARISON OF DILUTIONS TO A 10° BUFFER AND PREMIXED FLUIDS

4.4 COMPARISON WITH HOT CHARTS.

Current HOT time guidelines for Type I fluids under snow conditions are 6 to15 minutes at all temperature ranges [5]. Figure 19 shows the holdover time guideline range with respect to the January to March 2002 outdoor snow data obtained at AMIL and APS Aviation using the wing leading edge thermodynamic equivalent box. The holdover time guideline ranges are normally determined as the lowest times obtained at 10 and 25 g/dm²/h. Using this methodology, the outdoor data obtained above -3°C surpasses the 6- to 15-minute limit. The -3° to -10°C data would be lower than this limit, with a range of 6 to 8 minutes. The outdoor data between -10° and -25°C indicates a holdover time range of 2 to 4 minutes.

Type I Outdoor Snow Tests

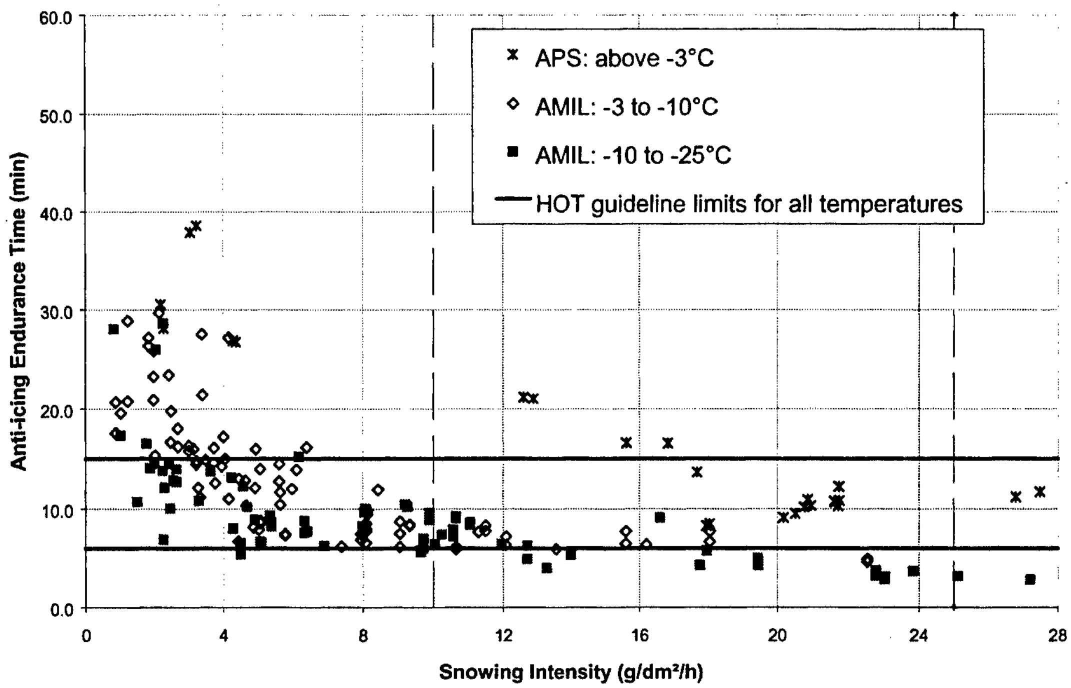


FIGURE 19. COMPARISON OF AMIL DATA WITH THE HOT GUIDELINE TABLES

5. CONCLUDING REMARKS.

Type I aircraft deicing fluid outdoor natural snow tests were conducted on wing leading edge thermodynamic equivalent boxes. The tests showed that:

1. There were only slight differences in endurance times between the fluids and, given the scatter of the results, it can be considered within acceptable limits.

2. Tests were conducted at two test sites and, taking into consideration the colder test temperatures at AMIL, the results were complementary.

3. Tests were conducted on Type I fluids diluted to a 10° buffer with the outside air temperature, as well as in ready-to-use premix form, with much lower freeze points. It was found that, in general, the premix fluids endurance times were 20% longer.

4. The data showed that the protection time provided by the fluids in the

   - above 0°C temperature range is 11 to 18 minutes
   - 0° to -3°C temperature range is 6 to 11 minutes
   - -3° to -10°C temperature range is 4 to 7 minutes
   - below -10°C temperature range is 2 to 4 minutes

6. RECOMMENDATIONS.

The procedure for generating fluid endurance times on a representative wing leading edge thermodynamic equivalent box can effectively and conveniently be performed under outdoor natural snow conditions. The recommended next step is to develop a similar test that could be conducted indoors, possibly using similar wing leading edge thermodynamic equivalent boxes.

7. REFERENCES.

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2. Dawson, P., "SAE Type I Fluid Endurance Time Test Protocol," Prepared for the Transport Development Centre, Transport Canada TP 13827, October 2001.

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